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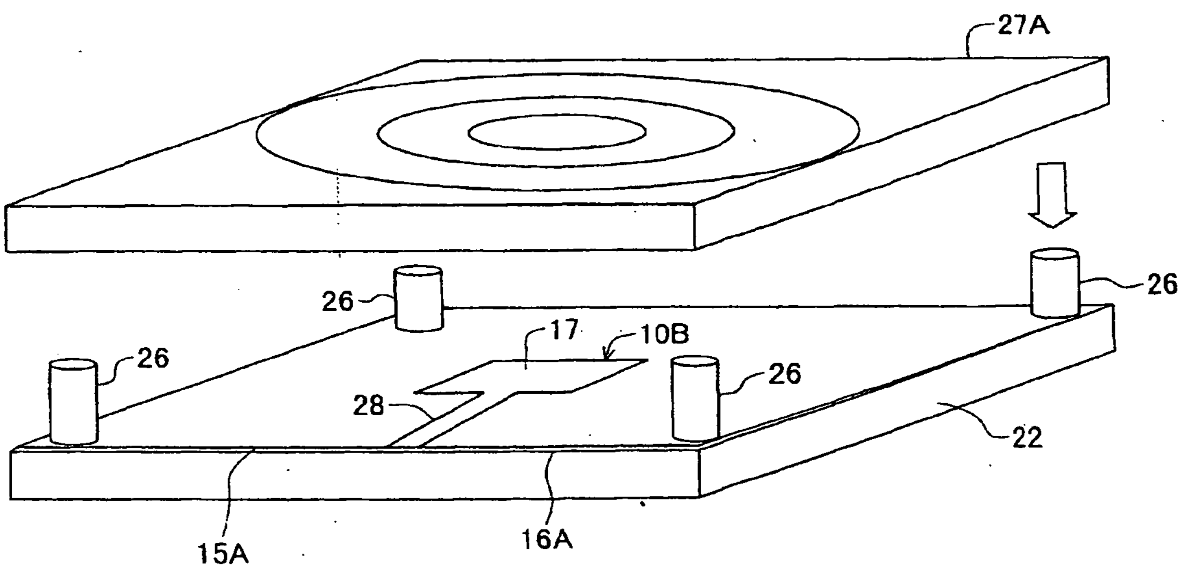
(54) **Patch antenna with dielectric separated from patch plane to increase gain**

(57) In a patch antenna (10A) for use in millimeter wave communications, a dielectric member (27,27A) with a thickness of from 0.1λ to 2λ is disposed opposite to a patch plane (17) and spaced from the patch plane (17) by a distance of from $0.1\lambda_0$ to $2\lambda_0$, where λ_0 and λ are the wavelengths of radiated radio waves in free space and in the dielectric member, respectively. The dielectric constant of the dielectric member (27,27A) may be lower in an outer portion thereof than a middle portion thereof. The antenna may be incorporated into a communication module, where the dielectric member (27,27A) is attached to the cover (32) of the communication module. The patch antenna has high gain with a simple configuration.

FIG.6



Description

[0001] The present invention relates generally to a patch antenna with a dielectric separated from a patch plane, and more particularly, to a patch antenna with a dielectric plate separated from a patch plane by an air gap to increase the gain of the antenna for a millimeter wave frequency range from 30 to 300 GHz and microwave frequencies near the millimeter wave frequencies.

[0002] A patch antenna is thin and compact in shape, so the antenna is used in millimeter wave radio communication. In the present specification, a patch antenna is defined as an antenna including a patch plane provided with high frequency power for radiating radio waves and a ground plane separated from the patch plane, with the patch plane and the ground plane generally formed on opposed surfaces of a dielectric substrate. Since in the millimeter wave band, patch antennas have low gain, the gain has been improved by use of an array configuration or a dielectric lens.

[0003] However, an array antenna has a plurality of patch planes arranged on a dielectric substrate and there is a necessity for supplying power to respective patch planes whilst controlling the values and phases thereof and in addition, for distributing the power supply through a micro strip line along which power transfer loss is comparatively large for millimeter waves; therefore it is not easy to provide the required characteristics. Further, when a dielectric substance which is low in power transfer loss is selected, the cost of the antenna increases. Furthermore, since it is necessary to space patch planes apart from each other by a distance equal to or more than 0.5λ to λ, where λ is the wavelength of waves radiated from the antenna, the area of an array antenna is relatively large.

[0004] In order to improve the gain of a patch antenna using a dielectric lens, it is necessary for a lens to be larger than the angular aperture of the patch antenna, and, since this angular aperture is generally wide, a large lens is necessary. Moreover, in order to obtain a high efficiency antenna, alignment precision between the patch antenna and the dielectric lens has to be high, which in turn requires high levels of precision in assembly and inspection, leading to a high cost.

[0005] In order to solve such problems with using a patch antenna, there is disclosed in JP 6-809715 A an antenna as shown in FIG. 10.

[0006] A patch antenna 10 is disposed between a reflection plate 11 and a dielectric block 12 at a spacing from the reflection plate 11. A spacer 13 is placed between the reflection plate 11 and the dielectric block 12 and a micro strip line 14 is connected to the patch plane of the patch antenna 10.

[0007] The publication discloses that gain can be increased by making multiple reflections, between the reflection plate 11 and the dielectric block 12, of radio waves radiated from the patch antenna 10 and aligning the phase planes of radio waves transmitted through the dielectric block 12 so as to increase the directivity of the antenna, and further by resonating the radio waves in the dielectric block.

[0008] In the antenna of FIG. 10, however, not only the dielectric block 12 but also the reflection plate 11 has to be added to the patch antenna 10, and moreover it is necessary to optimize the distance between the patch antenna 10 and the dielectric block 12, the thickness of the dielectric block 12, and further the distance between the patch antenna 10 and the reflection plate 11.

[0009] Accordingly, embodiments of the present invention provide an improved patch antenna capable of increasing the gain with simpler configuration.

[0010] According to one aspect of the invention there is provided an antenna comprising: a patch antenna including: a patch plane provided with high frequency power to radiate radio waves; and a ground plane separated from the patch plane opposite to the patch plane; and a dielectric member disposed on the patch plane side of the patch antenna opposite to the patch plane with a distance of $0.1\lambda_0$ to $2\lambda_0$ from the patch plane, where λ_0 denotes a wavelength of radio waves, in free space, radiated from the antenna. A plane located opposite to the patch antenna on the opposite side to the dielectric member with respect to the patch antenna may be either a non-conductive plane or a conductive plane. In the case of the conductive plane, it is not necessary to adjust distances between the patch antenna, the dielectric member and the conductive plane so as to make phases of radiated radio wave coincident as in the above described prior art configuration. The conductive plane is separated from the dielectric member by such a distance that the phases of radio waves directly incident on the surface of the dielectric member are substantially different from those of radio waves indirectly incident on the surface after having been reflected by the conductive plane.

[0011] According to embodiments of the present invention, by providing high frequency power to the patch antenna, radio waves are radiated from the patch plane and pass through the dielectric member. The dielectric member is polarized by the electromagnetic wave and an electromagnetic field is set up in the patch plane by the dielectric member which changes the current distribution in the patch plane. By determining (setting) the distance between the dielectric member and the patch plane as described above, (it is found that) the current density grows larger mainly at a peripheral portion of the patch plane compared with a case where no dielectric substrate is employed. Thereby directivity arises in the electromagnetic radiation pattern on the patch plane to increase the gain. The current distribution on the patch plane is controlled such that the directivity arises in the electromagnetic radiation pattern to increase the gain by operation of the dielectric member.

[0012] The principle of the present invention for achieving high gain is different from that of the known configuration employing the reflection plate 11 as shown

in FIG. 10, in that there is no need to employ a reflection plate 11 whose position is precisely adjusted; therefore the patch antenna of the first embodiment can increase the gain with a simpler configuration. That is, in the known configuration shown in Fig. 10, strict positioning of the reflection plate 11 and others is required in order to make phases coincident between a radio wave directly transmitted through the dielectric member after having been radiated from the patch antenna and radio waves indirectly transmitted through the dielectric member after having been reflected by the reflection plate 11, whereas the present invention requires no such positioning even when the conductive plane is provided. A characteristic feature of the present invention is to achieve high gain of the antenna with increasing current densities at a peripheral portion of the patch plane by the dielectric member.

[0013] In order to realize the present invention, it is only required that a dielectric member is disposed on the patch plane side of the patch antenna opposite to the patch plane with a distance of $0.1\lambda_0$ to $2\lambda_0$ from the patch plane, and a plane located opposite to the patch antenna on the opposite side to the dielectric member with respect to the patch antenna may be a non-conductive plane, that is, a non-reflective plane. In a case where the plane is a conductive plane, it is separated from the patch antenna or the dielectric member by such a distance that the phases of the radio waves directly incident on the surface of the dielectric member are substantially different from the phases of radio waves indirectly incident on the surface after having been reflected by the conductive plane. In order to realize the substantially different phases, the phases of both types of radio waves may be determined, and these phases made substantially different from each other, for example, opposite (in anti-phase) to each other. In the design of the antenna, it may be arranged that a simulation of the radiation pattern on the patch plane is performed taking into consideration dielectric constants of respective portions of the antenna, and the phase shifts of radio waves passing through the respective portions, and the phase condition derived from the results of the simulation.

[0014] According to an embodiment of the present invention, the dielectric member of the antenna has a thickness of from 0.1λ to 2λ, where λ is the wavelength of radiated radio waves in the dielectric member.

[0015] According to this embodiment, the electromagnetic field induced on the patch plane of the antenna from the dielectric member is strengthened compared with a case where the thicknesses falls outside this range, and thereby the above effect is enhanced.

[0016] In another embodiment of the present invention, the dielectric member of the antenna has a first dielectric in a middle portion thereof and a second dielectric disposed around the middle portion with a dielectric constant lower than that of the first dielectric in the previous embodiment.

[0017] According to this embodiment, since the dielectric member of the antenna also works as a dielectric lens, directivity is increased more than in the previous embodiment, thereby increasing the gain of the antenna.

[0018] In a second aspect of the invention there is provided a communication module comprising: a conductive substrate; an antenna mounted on the conductive substrate; and a communicating MMIC mounted on the conductive substrate and connected to the antenna. The antenna comprises a patch antenna including: a patch plane; and a ground plane separated from the patch plane opposite to the patch plane; wherein high frequency power is provided to the patch plane to radiate radio waves; and a dielectric member disposed on the patch plane side of the patch antenna opposite to the patch plane with a distance of $0.1\lambda_0$ to $2\lambda_0$ from said patch plane, where λ_0 denotes a wavelength of radio waves, in free space, radiated from the antenna; wherein the ground plane is contacted with a surface of the conductive substrate, wherein the dielectric member is separated from the surface by such a distance that the phase of the radio waves directly incident on a surface of the dielectric member is substantially different from that of radio waves indirectly incident on the surface after having been reflected by the conductive substrate.

[0019] In this aspect, since the dielectric member is attached to the cover of the communication module, high gain of the antenna can be achieved with substantially the same size as a prior art patch antenna.

[0020] Reference will now be made, by way of example only, to the following drawings, in which:

FIG. 1 is an exploded perspective view of an improved patch antenna of a first embodiment according to the present invention;

FIG. 2 is a partial cross-sectional view of the assembled antenna of FIG. 1;

FIG. 3 is a radiation pattern diagram showing a directivity of a patch antenna obtained by excluding a dielectric substrate from the configuration of FIG. 1;

FIG. 4 is a radiation pattern diagram showing a directivity of the improved patch antenna of FIG. 1;

FIG. 5 is a partially exploded perspective view of an improved patch antenna of a second embodiment according to the present invention;

FIG. 6 is a partially exploded perspective view of an improved patch antenna of a third embodiment according to the present invention;

FIG. 7 is a perspective view showing a cross-section of a dielectric member 27A of FIG. 6;

FIG. 8(A) is a plan view of a communication module employing the antenna of FIG. 5;

FIG. 8(B) is a partially cross-sectional view taken along line 8B-8B in FIG. 8(A);

FIG. 9 is a schematic block diagram of an MMIC of FIG. 8; and

FIG. 10 is a perspective view showing a prior art

high gain patch antenna.

[0021] In the drawings like reference characters designate like or corresponding parts throughout several views. Preferred embodiments of the present invention are described below.

[0022] FIG. 1 is an exploded perspective view of an improved patch antenna of a first embodiment according to the present invention, and FIG. 2 is a partial cross-sectional view of the assembled antenna.

[0023] A patch antenna 10A has a dielectric substrate 15, and on opposite surfaces thereof, a ground plane 16 and a patch plane 17 are respectively formed. The dielectric substrate 15 is made of, for example, SiO_2 and has a thickness of from 200 to 500 μm. Each of the ground plane 16 and the patch plane 17 is made of a metal film having a thickness of several μm. The patch plane 17 has a side of length $\lambda_0/2$, where λ_0 is a wavelength of a radiated radio wave in free space.

[0024] A hole is formed in a middle portion of the dielectric substrate 15, a core conductor 20 of a coaxial cable 19 runs through the hole and an end of the core conductor is soldered to the patch plane 17. Corresponding to this hole, a hole 23 is formed in a supporting substrate 22 and the end of the central conductor of the coaxial cable 19 runs through the hole 23 and the end thereof is fixed to the supporting substrate 22. The outside conductor of the coaxial cable 19 is connected to the ground plane 16. The supporting substrate 22 is an insulator and a dielectric member 27 is fixed to the supporting substrate 22 through spacers 26 arranged at corners thereof.

[0025] The dielectric member 27 is made of, for example, Al_2O_3 and has a thickness of from 0.1λ to 2λ, where λ is the wavelength of a radiated radio wave in the dielectric member 27. The distance between the dielectric member 27 and the patch plane 17 is preferably in the range of from 0.1λ to 2λ to achieve a high gain. This is described in more detail later.

[0026] Radiation patterns were measured on the improved patch antenna of the above-described configuration in cases where the dielectric member 27 was not used and was used, and the results shown in FIGS. 3 and 4, respectively, were obtained. In this experiment, the same high frequency power was provided to the patch antenna 10A in both cases where the dielectric member 27 was not used and was used. The radio wave with the highest intensity had a frequency of 59.8947 GHz.

[0027] In FIGS. 3 and 4, the scale in a radial direction is the gain (dBi) and the scale in a circular direction is the angle θ with respect to the direction of the core conductor 20. The radiation angle is a central angle between two points each having a gain lower than the maximum gain by 3 dB, and the radiation angles of FIGS. 3 and 4 were about 60 degrees and about 30 degrees, respectively. The antenna gains of FIGs.3 and 4 were 7 dBi and 15 dBi, respectively. As a result, according to the antenna of the first embodiment, the directivity thereof is improved with increase in gain.

[0028] The reason why such an effect is obtained is as follows: When high frequency power is provided through the coaxial cable 19 to the antenna 10A, radio waves are radiated from the patch plane 17 and transmitted through the dielectric member 27. By the radio waves, the dielectric member 27 is polarized and an electromagnetic field is produced between the patch plane 17 and the dielectric member 17 changing the current distribution in the patch plane 17. By determining (setting) the distance between the patch plane 17 and the dielectric member 27 as described above, (it is found that) current densities grow larger mainly at the peripheral portion of the patch plane than in a case where no dielectric member 17 is employed. With this, the directivity arises in an electromagnetic radiation pattern to improve the gain. That is, by the presence of the dielectric member 27, the current distribution on the patch plane 17 is controlled such that the directivity arises in an electromagnetic radiation pattern to improve the gain.

[0029] A simulation was performed to confirm how much current density on the patch plane is increased by placing the dielectric member 27 as described above, and the following results were obtained:

[0030] In cases where the dielectric member 27 was not disposed and was disposed apart from the patch plane 17 by 3λ, the current distributions on the patch plane 17 were almost uniform.

[0031] In a case where the dielectric member 27 was disposed apart from the patch plane 17 by 0.4λ, the current distribution on the patch plane 17 had current densities of about twice and thrice as large as when the dielectric member 27 was not disposed, at the middle and peripheral portions, respectively, of the patch plane 17.

[0032] In a case where the dielectric member 27 was disposed apart from the patch plane 17 by a distance from 0.1λ to 2λ, the current density increased, especially, at a peripheral portion of the patch plane 17 more than a case where the dielectric member 27 was not present.

[0033] In the improved patch antenna of the first embodiment, the principle for achieving high gain is different from that of the configuration employing the reflection plate 11 as shown in FIG. 10, and there is no need to employ the reflection plate 11; therefore the patch antenna of the first embodiment can increase the gain with a simpler configuration than that of the prior art.

[0034] Furthermore, by determining the thickness of the dielectric member 27 in the range as described above, the electromagnetic field provided onto the patch plane 17 from the dielectric member 27 is strengthened more than the case where the thickness is out of the range, thereby enhancing the above described effect.

[0035] Still further, since the dielectric member 27 is not a lens but a flat plate, no axial alignment is required between the patch antenna 10A and the dielectric mem-

ber 27. In addition, the dielectric member 27 has no focus, so there is no need to precisely determine a distance between the dielectric member 27 and the patch antenna 10A. Therefore, high levels of precision in techniques associated with assembly and inspection are not required, thereby reducing the cost in comparison with a case where a dielectric lens is employed.

[0036] FIG. 5 is a partially exploded perspective view of an improved patch antenna of a second embodiment according to the present invention.

[0037] In a patch antenna 10B, a ground plane 16A has the same area as the supporting substrate 22, and high frequency power is provided to the patch plane 17 through a micro strip line 28 formed on a dielectric substrate 15A.

[0038] The other points are the same as those of the first embodiment.

[0039] A similar effect to the first embodiment can also be obtained by the second embodiment.

[0040] FIG. 6 is a partially exploded perspective view of an improved patch antenna of a third embodiment according to the present invention.

[0041] This antenna employs a dielectric member 27A instead of the dielectric member 27 of FIG. 5.

[0042] FIG. 7 is a perspective view showing a cross-section of the dielectric member 27A of FIG. 6.

[0043] The dielectric member 27A is constructed of a circular (disc-shaped) dielectric 271 in the central portion, annular dielectrics 272 and 273 around the circular dielectric 271, and an outermost dielectric 274. The dielectric constants of the dielectrics 271 to 274 are different from each other and increase from the inner to the outer dielectric. With such a configuration, the dielectric member 27A also works as a dielectric lens, and therefore the directivity is improved compared with the second embodiment to increase the gain of the antenna.

[0044] Next, a description will be given of a case where a conductive surface is disposed on the ground plane side of a patch antenna, as a fourth embodiment according to the present invention.

[0045] FIG. 8(A) is a plan view of a communication module employing the antenna of FIG. 5, and FIG. 8(B) is a partial cross-sectional view taken along line 8B-8B in FIG. 8(A).

[0046] In this communication module, the patch antenna 10B of FIG. 5 is soldered on the conductive substrate 30 with its ground plane in contact with the substrate 30. On the substrate 30, a plurality of MMICs 31 are soldered and one of the plurality of MMICs 31 and the patch antenna 10B are connected by bonding wires. On the substrate 30, a cover 32 is fixedly mounted so as to cover the patch antenna 10B and the MMICs 31. An opening is formed in the cover 32 above the patch antenna 10B and the dielectric member 27 is fixedly attached around the opening. Pins 33 projected outward from the substrate 30 are for use in feeding power and signals to the MMICs 31.

[0047] In the fourth embodiment, the ground plane is in contact with the conductive surface of the substrate 30, and reflected radio waves from the surface of the substrate 30 and direct radio waves radiated from the patch antenna 10B to the dielectric member 27 have substantially different phases from each other at the incident surface of the dielectric member 27. Since it is not easy to make the phases coincident with each other, this condition of the different phases is usually established automatically unless positioning is intentionally performed so as to achieve coincidence between the phases. Especially, if the waves are designed to be in anti-phase, the above-described condition can be easily established even if the parts thereof are in poor dimensional precision.

[0048] FIG. 9 is a schematic block diagram of the MMIC 31.

[0049] In the MMIC 31, the output of a local oscillator 311 and a signal IFin of intermediate frequencies are provided to a mixer 312 to shift the frequencies of the signal IFin to the upper and lower sides, and the upper side component passes through a band pass filter 313 and is then amplified by an amplifier 314 to be supplied to a patch antenna 10A through a switching circuit 315. In the case of reception, a received signal is provided from the antenna 10A through the switching circuit 315 to the amplifier 316, amplified in the amplifier 316 and sent to a mixer 317 to raise and lower the frequency of this provided signal by a frequency of a signal from a local oscillator 318, and the lower side component passes through a band pass filter 319 to output a signal IFout of intermediate frequencies.

[0050] According to the fourth embodiment, since the dielectric member 27 is attached to the cover of the communication module, high gain of the antenna can be achieved with substantially the same size patch antenna as is used in the prior art.

[0051] Although preferred embodiments of the present invention has been described, it is to be understood that the invention is not limited thereto and that various changes and modifications may be made without departing from the scope of the invention.

[0052] For example, a patch antenna employed in the present invention may have various shapes of patch plane such as a shape having a notch or a slot and a circular shape, and further a power feeding point to supply a patch plane with power may be determined according to applications.

Claims

1. An antenna comprising:

   a patch antenna (10A, 10B) including: a patch plane (17) provided with high frequency power to radiate radio waves; and a ground plane (16,16B) separated from said patch plane (17) opposite to said patch plane; and

a dielectric member (27,27A) disposed on the patch plane side of said patch antenna (10A, 10B) opposite to said patch plane (17) with a distance of $0.1\lambda_0$ to $2\lambda_0$ from said patch plane (17), where λ_0 denotes a wavelength of radio waves, in free space, radiated from said antenna;

wherein a plane located opposite to said patch antenna (10A.10B) on the opposite side to said dielectric member (27.27A) with respect to said patch antenna (10A,10B)is either a non-conductive plane or a conductive plane, wherein said conductive plane (22) is separated from said dielectric member (27.27A) by such a distance that the phase of said radio waves directly incident on a surface of said dielectric member (27.27A) is substantially different from that of radio waves indirectly incident on said surface after having been reflected by said conductive plane.

2. The antenna as claimed in claim 1, wherein said dielectric member (27,27A) has a thickness of from 0.1λ to 2λ, where λ is the wavelength of said radio waves in said dielectric member (27,27A).

3. The antenna as claimed in claim 1 or 2, wherein said dielectric member (27,27A)has a first dielectric in a middle portion thereof and a second dielectric disposed around said middle portion with a dielectric constant lower than that of said first dielectric.

4. The antenna as claimed in any preceding claim, further comprising a dielectric substrate (15) interposed between said patch plane (17) and said ground plane (16,16A).

5. The antenna as claimed in claim 4, wherein said dielectric member (27,27A) is a substrate arranged substantially parallel to said dielectric substrate (15).

6. The antenna as claimed in any preceding claim, wherein said dielectric member (27,27A) is separated from said patch plane (17) by an air gap.

7. The antenna as claimed in any preceding claim, further comprising: a supporting substrate (22) for mounting said patch antenna (10A,10B), wherein said non-conductive plane is a surface of said supporting substrate (22).

8. The antenna as claimed in claim 7, wherein said ground plane (16,16A) is contacted with said surface of said supporting substrate (22).

9. A communication module comprising:

a conductive substrate (30);
an antenna (10B) mounted on said conductive substrate; and
a communicating MMIC (31) mounted on said conductive substrate and connected to said antenna (10B) ;

wherein said antenna comprises:

a patch antenna including: a patch plane; and a ground plane (16,16A) separated from said patch plane (17) opposite to said patch plane; wherein high frequency power is provided to said patch plane to radiate radio waves; and
a dielectric member (27,27A) disposed on the patch plane side of said patch antenna opposite to said patch plane with a distance of $0.1\lambda_0$ to $2\lambda_0$ from said patch plane, where λ_0 denotes a wavelength of radio waves, in free space, radiated from said antenna;

wherein said ground plane is contacted with a surface of said conductive substrate,
wherein said dielectric member is separated from said surface by such a distance that the phase of said radio waves directly incident on a surface of said dielectric member is substantially different from that of radio waves indirectly incident on the surface after having been reflected by said conductive substrate.

10. The communication module as claimed in claim 9, wherein said dielectric member (27,27A) has a thickness of from 0.1λ to 2λ, where λ is a wavelength of said radio waves in said dielectric member.

11. The communication module as claimed in claim 9 or 10, further comprising:

a cover (32), mounted on said conductive substrate (30) so as to cover said antenna (10B) and said MMIC (31), having an opening at a portion corresponding to said antenna (10B) ;

wherein said dielectric member (27,27A) of said antenna is attached around said opening at a peripheral portion of said dielectric member.

FIG.1

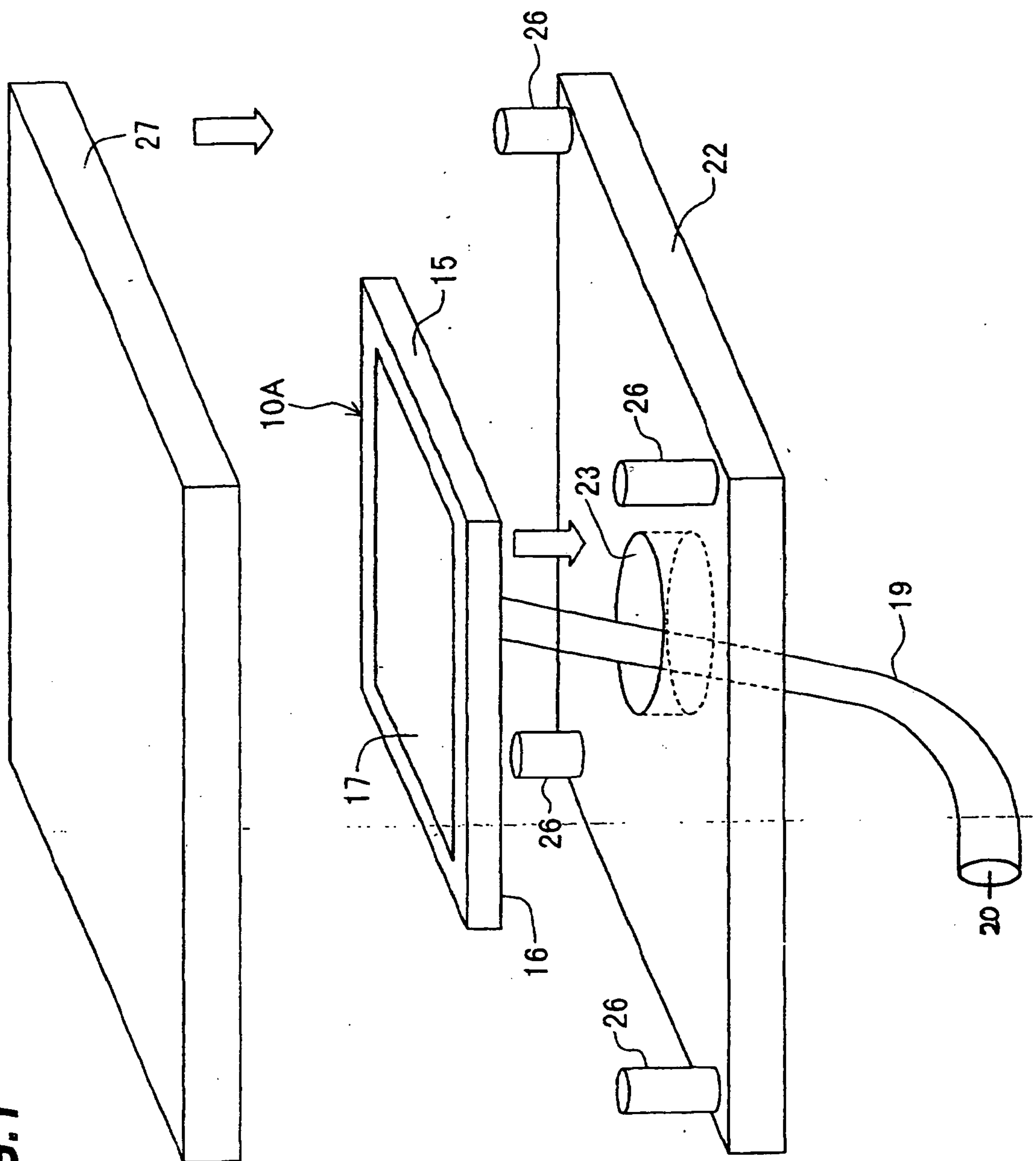


FIG.2

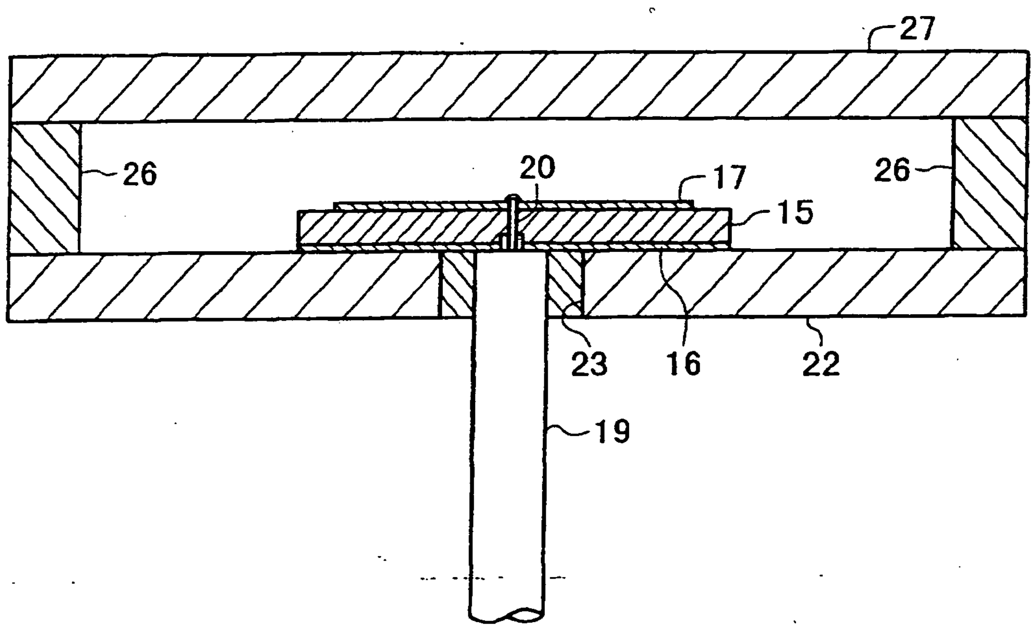


FIG.3

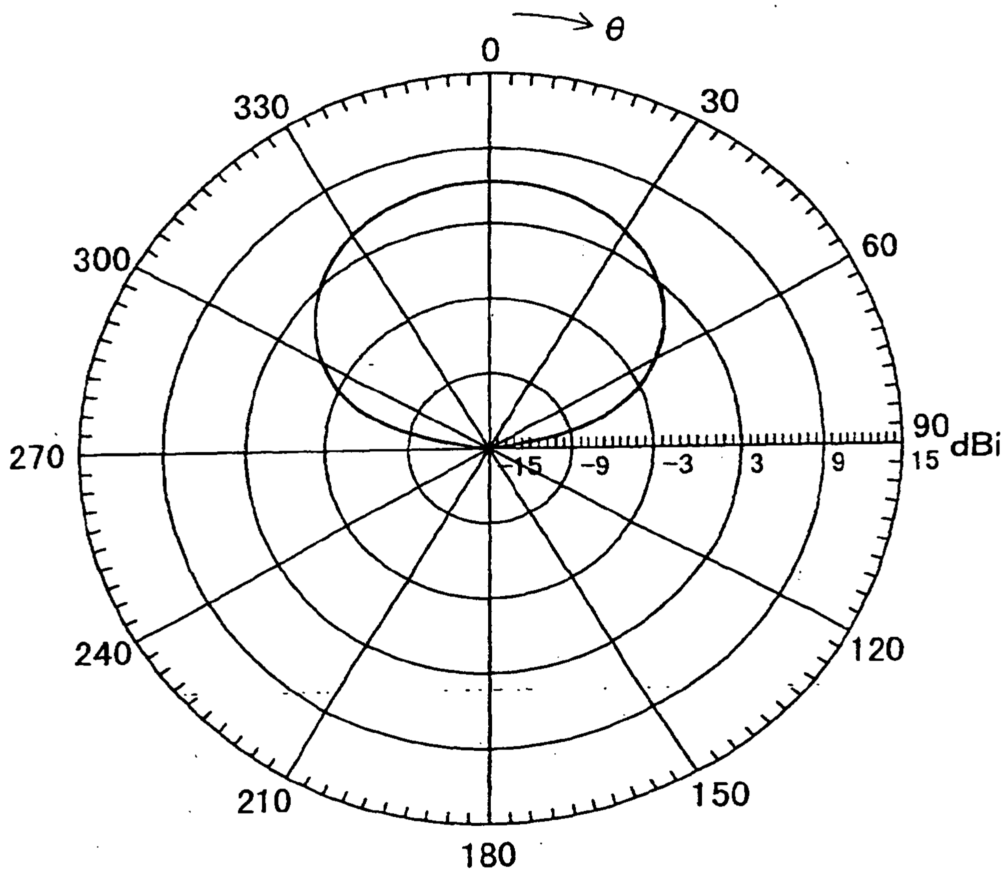


FIG.4

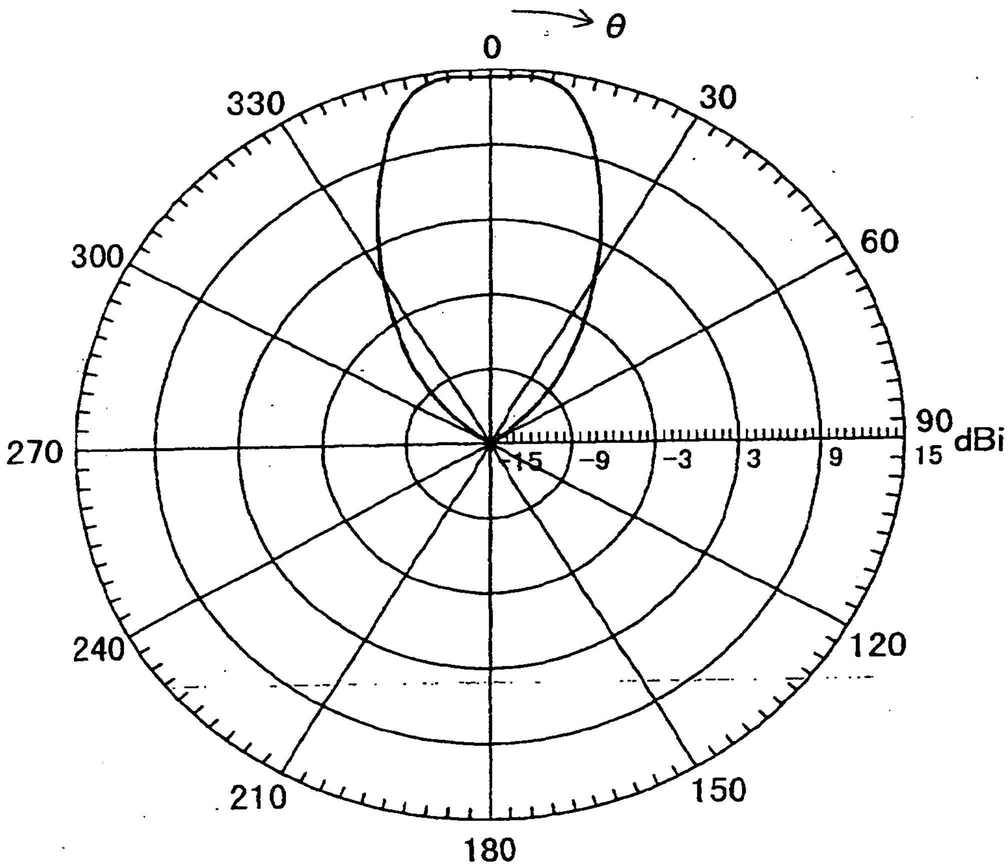


FIG.5

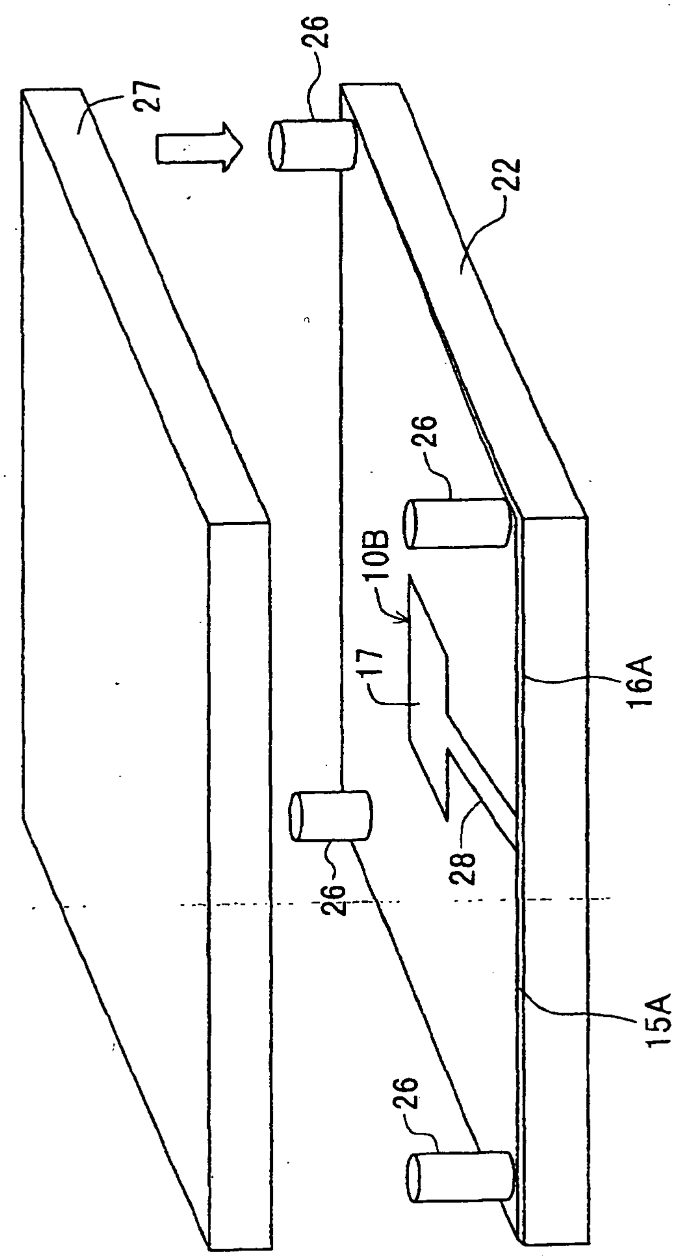


FIG.6

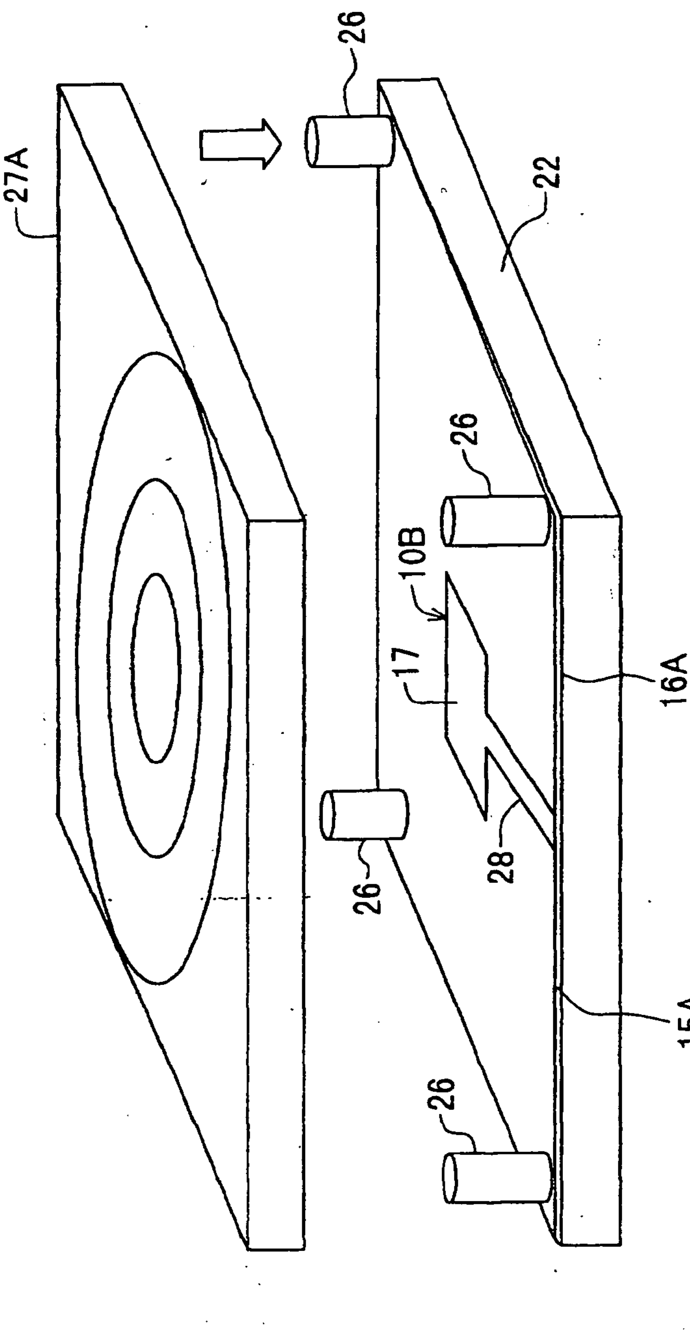


FIG.7

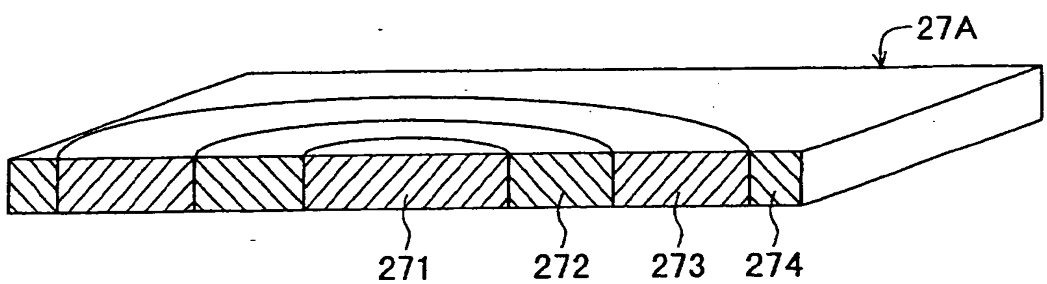


FIG.8A

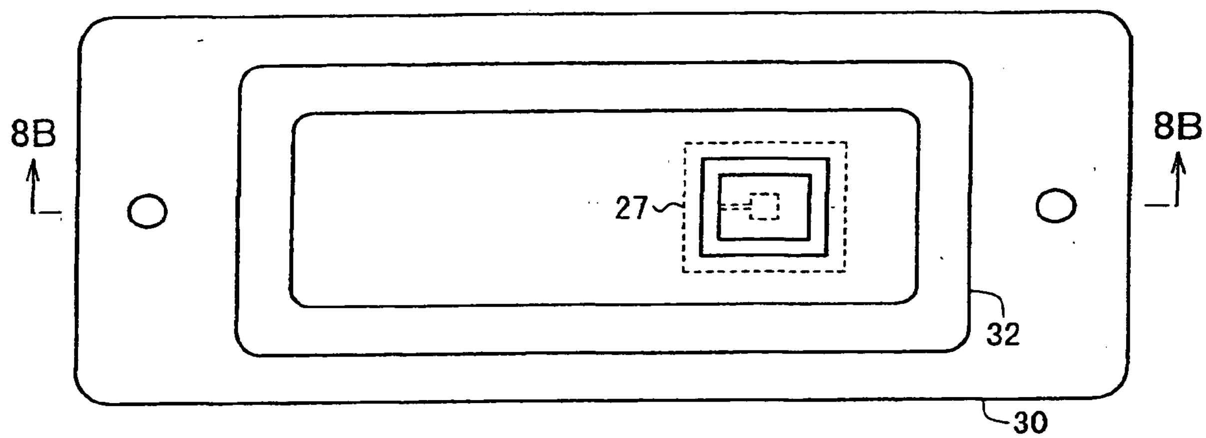


FIG.8B

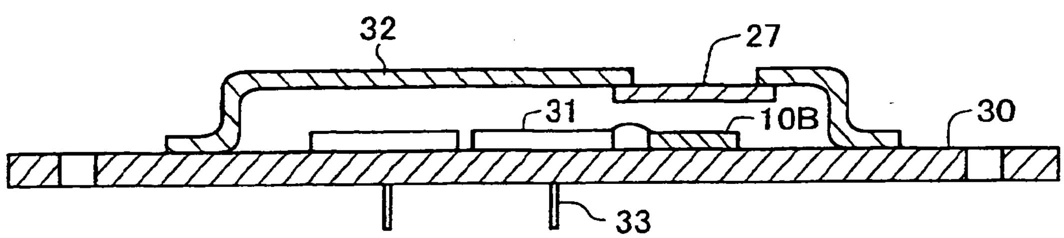


FIG.9

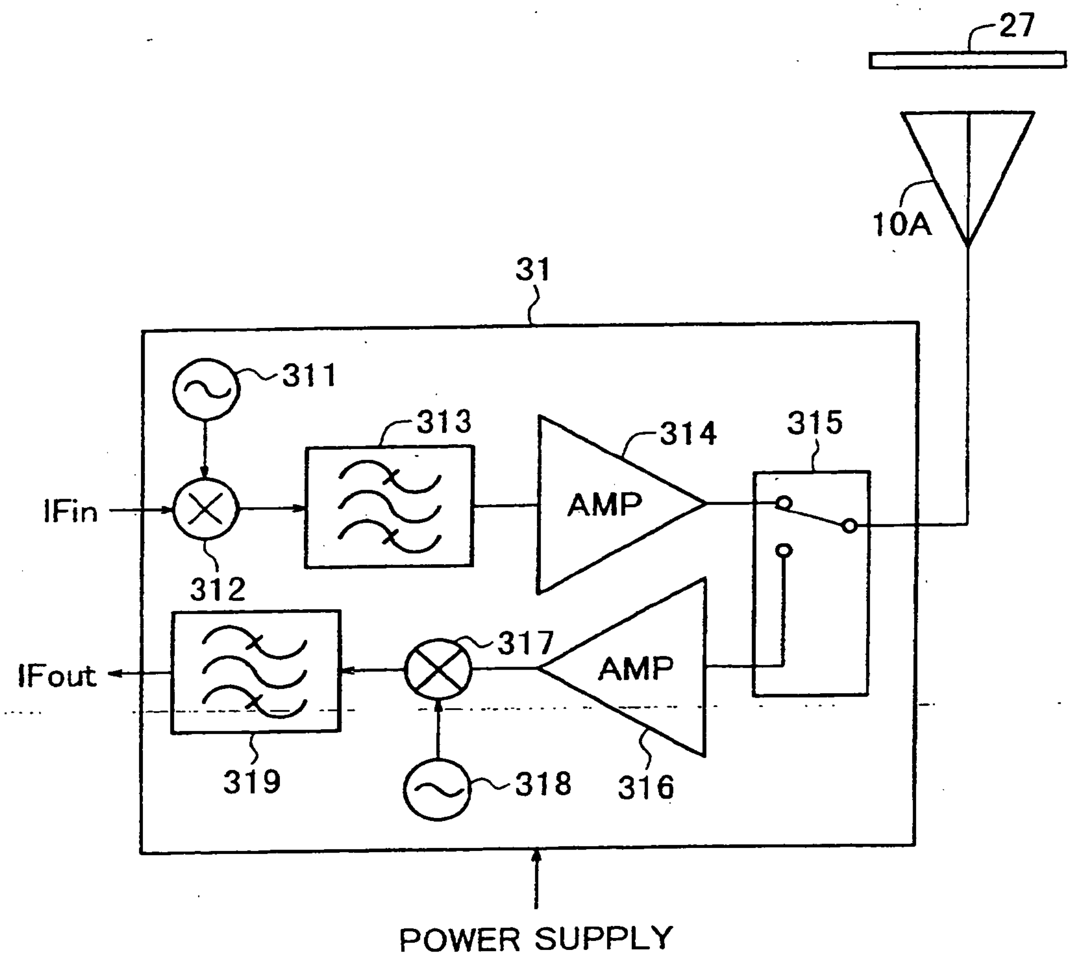
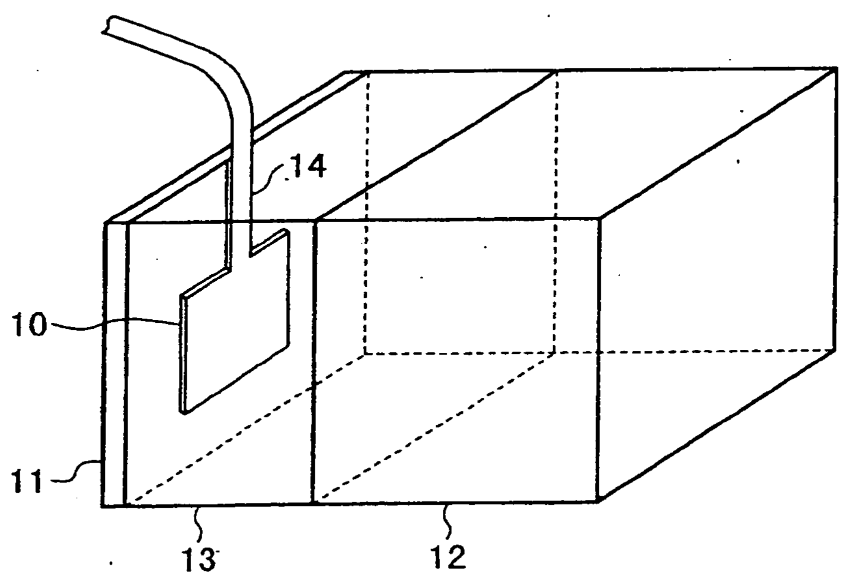

27
10A
31
311
313
314
315
IFin
AMP
312
317
IFout
AMP
319
318
316
POWER SUPPLY

FIG.10
prior art



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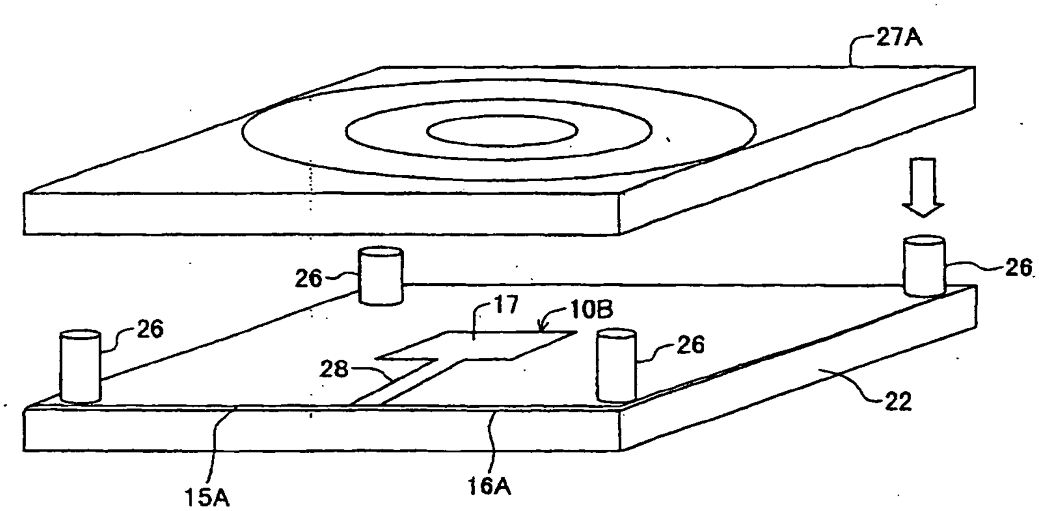
(54) **Patch antenna with dielectric separated from patch plane to increase gain**

(57) In a patch antenna (10A) for use in millimeter wave communications, a dielectric member (27,27A) with a thickness of from 0.1λ to 2λ is disposed opposite to a patch plane (17) and spaced from the patch plane (17) by a distance of from $0.1\lambda_0$ to $2\lambda_0$, where λ_0 and λ are the wavelengths of radiated radio waves in free space and in the dielectric member, respectively. The dielectric constant of the dielectric member (27,27A) may be lower in an outer portion thereof than a middle portion thereof. The antenna may be incorporated into a communication module, where the dielectric member (27,27A) is attached to the cover (32) of the communication module. The patch antenna has high gain with a simple configuration.

FIG.6



EP 1 193 795 A3

European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 01 30 8176

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Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.7)
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The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
MUNICH	10 June 2003	Dollinger, F

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